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U.S. Nuclear Regulatory Commission
Division of Waste Management
Washington, D.C. 20555

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Dear David:

Enclosed is our review of "Modification of Rock Mass Permeability in the Zone Surrounding a Shaft in Fractured, Welded Tuff" by John B. Case and Peter C. Kelsall (SAND86-7001). Please call me if you have any questions.

Sincerely,

Roger D. Hart

Roger D. Hart
Program Manager

cc: R. Ballard, Engineering Branch
Office of the Director, NMSS
E. Wiggins, Division of Contracts
DWM Document Control Room

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ITASCA DOCUMENT REVIEW

File No.: 001-02-35

Document Title: "Modification of Rock Mass Permeability in the Zone Surrounding a Shaft in Fractured, Welded Tuff" by John B. Case and Peter C. Kelsall (SAND86-7001, March 1987)

Reviewer: Itasca Consulting Group, Inc. (L. Lorig)

Approved: J Daemen

Date Approved: 5-24-87

Significance to NRC Waste Management Program

This document presents DOE's present approach for estimating a modified permeability zone in the rock mass surrounding shafts in the welded tuffs of the Topopah Spring unit at Yucca Mountain. Estimates of the permeability in rock are necessary to evaluate the need for and performance of the sealing subsystem. [The technical criteria developed by NRC include the provision that "seals for shafts and boreholes shall be designed so that following permanent closure they do not become pathways that compromise the geologic repositories ability to meet the performance objectives . . ." (10 CFR 60.134(a))]. Estimates of the permeability are also used in performance analyses related to determination of QA levels for the shafts. DOE's original performance analysis related to determination of QA levels for the Exploratory Shaft (ES) was presented in a letter from D. L. Vieth to J. J. Linehan, 15 July 1985. Appendix B of this letter gave a simplified model in which the hydraulic conductivity was increased by two orders of magnitude uniformly over a zone extending to one radius of the shaft wall, as shown in Fig. 1.

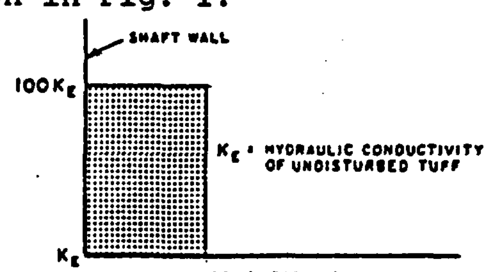

Fig. 1 Simplified Damaged Zone Model Used in Original Performance Analysis Study Presented in Appendix B of Letter from D. L. Vieth to J. J. Linehan (15 July 1985)

This model was not based on a "site-specific evaluation of the degree of damage likely to be associated with shaft construction in tuff" (Vieth, Appendix B, p. 5). Subsequently, NRC requested DOE to provide it "with the data (e.g., RQD's, stresses, hydraulic conductivities used to get the results presented during DOE presentation of the damaged zone model for tuff" (Open Item 18 of NRC-NNWSIP Exploratory Shaft Design Construction Meeting Summary, August 27-28, 1985).

The stated objective of the present document is "to develop a model of permeability changes as a function of radial distance from a shaft" (abstract). Two mechanisms are considered for modifying the permeability adjacent to the shaft: stress redistribution and damage by the excavation process (i.e., blasting). No new fractures are assumed to be created as a result of stress redistribution but fractures are assumed to result from blasting. The document is limited to consideration of flow through fractures and is written in terms of modification or rock mass permeability relative to undisturbed conditions. Values of undisturbed rock mass permeability are not cited. The authors point out that the term "rock mass permeability" implies a property of the rock mass (i.e., intrinsic permeability) which does not depend on the fluid permeant. They suggest that the "modified permeability zone model which is developed can be applied to water flow (in saturated conditions) or air flow (in unsaturated conditions) through fractures" (p. 9).

The methodology used to develop the model is based on an approach used previously for a shaft in basalt (Kelsall et al, 1982). The calculations presented in this report use site-specific (i.e., Topopah Spring) properties in computing stress redistribution resulting from excavation, but no site-specific properties are used in estimating the amount of increased permeability resulting from blasting. Parameters used in computing the post-excavation stress distribution include the unconfined compressive strength, in-situ stress state, and rock mass rating (RMR). Values for these parameters were taken from the following sources:

(1) Nimick et al (1984) for unconfined compressive strength;

(2) Nimick et al (1984) for value of ν to be used to estimate in-situ stress; and

upper bound, $\sigma_{horizontal} = \rho gh)$

lower bound, $\sigma_{horizontal} = [\nu/(1-\nu)] \cdot (\rho gh)]$

(3) Langkopf and Gnirk (1986) for RMR.

Results are presented in table form (Table 4, p. 59) for a number of conditions at two depths (100 and 310 meters). This table shows that the equivalent permeability of the modified permeability zone, averaged over an annulus one radius wide around the shaft, ranges from 15 to 80 times the undisturbed rock mass permeability. The equivalent permeability is averaged over an annulus one radius wide around the 4.4m excavated diameter exploratory shaft.

No analyses are presented for depths below 310m. It is presently envisioned that ES-1 will extend well below that level in order to test properties of the Calico Hills unit. Permeability of the rock mass surrounding the shaft below 310m is therefore conceivably more important than that above the 310m level.

This document presents a very simple (almost "back-of-the-envelope") preliminary approach to a very complex problem. The methodology adopted in the analyses raises questions concerning the importance which should be attached to the reported values of equivalent permeability. These questions are discussed in detail in the section concerning problems, limitations and deficiencies of the report.

The document also gives a bibliography (in Appendix B) listing 64 documents which discuss, in some way, rock damage caused by blasting. NRC had asked DOE to "establish an authoritative set of references on the subject of rock damage around openings in earth" (Open Item #5, NRC-NNWSIP ES Design/Construction Meeting Summary, August 27-28, 1985). Whereas this bibliography is reasonably complete, it illustrates that hard field evidence, particularly in terms of permeability changes, is very limited. Whether the evidence provided by the references is sufficiently detailed and comprehensive to address all the technical issues related to blasting damage remains uncertain.

Summary

This report presents a methodology for developing a modified permeability zone model around shafts in fractured, welded tuff of the Topopah Spring unit of Yucca Mountain. This methodology is used to evaluate several assumptions involving in-situ stress state, blast damage, sensitivity of permeability to stress, and rock mass strength for a 4.4m diameter shaft. It involves the following steps.

(1) calculation of radial stress changes around a shaft using elastic and elasto-plastic closed-form solutions assuming a uniform stress field;

(2) review of published laboratory and field testing results which describe the effects of normal stress on the permeability of single fractures and determination of upper and lower bounds for the sensitivity of rock mass permeability to effective normal stress;

(3) calculation of rock mass permeability as a function of radial distance away from the shaft using results from (1) and (2);

(4) review of published literature and estimation of (1) depth of damage due to blasting from case histories, and (2) probable permeability increases over the increase in permeability due to stress redistribution (Note: A threefold increase was assumed without justification.); and

(5) combination of results from (3) and (4) to obtain effect of stress redistribution and blasting.

Results are presented for a 4.4m excavated diameter shaft at the 100m and 310m depth levels. The analyses indicate that, for the conditions evaluated, "the equivalent permeability of the modified permeability zone averaged over an annulus of one radius wide around the shaft, ranges from 15 to 80 times the undisturbed rock mass permeability".

Problems, Limitations, Deficiencies

General Comments — As mentioned previously, this report presents a very simple method for studying a very complex problem. The methodology adopted seems reasonable for preliminary analysis. The individual calculation methods and range of parameters (with the possible exception of intact rock strength) probably are also acceptable for a preliminary analysis. However, it must be kept in mind that methodology involves several simplifying assumptions and that there is no rigorous justification or quantification of the simplifying assumptions involved. These assumptions include:

(1) radial symmetry (with the exception of elastic analysis used to evaluate the potential for intact rock fracturing);

(2) rock mass strength and stiffness parameters (Blasting is assumed to result in a threefold increase in the modified permeability in the region immediately adjacent to the shaft but does not affect rock mass strength or stiffness. If blasting resulted in lower rock mass strength or stiffness, stress redistribution could affect a much larger annulus. The degree to which blasting affects rock mass strength and stiffness and permeability is speculative.);

(3) continuum rock mass behavior (governed by the Hoek-Brown empirical relation or linear elasticity);

(4) rock fracturing (No rock fracturing results from stress redistribution.); and

(5) thermal effects (These are ignored.).

Detailed Comments

1. Quantitative terms are seldom used to characterize the degree for fracturing. For example, on p. 56, it is stated that "intensely fractured zones might extend a small distance from perimeter drill holes". On the other hand, the rock mass is described on p. 1 as being "densely fractured". Quantitative terms are mentioned only in Section 2.1 (4th paragraph).

2. It is stated (p. 1, 2nd paragraph) that "The potential for fracturing of intact rock is evaluated by means of a simple analysis for the case of a circular shaft excavated in a homogeneous, isotropic and linear elastic medium. This analysis shows that the maximum tensile or compressive stresses at the shaft wall at repository depth should not exceed 10 percent of the reported mean values for tensile or compressive strength of intact rock." This argument is not convincing from the following perspectives:

   (a) The assumption of homogeneous isotropic material behavior results in a stress condition near the lower bound (i.e., other material behavior assumptions could result in at least locally higher stresses, even with the same in-situ stresses).

(b) The intact rock compressive strengths used in this report ("110 to 230 MPa, with an expected value of 171 MPa") are generally higher than values given in many references (e.g., Tillerson and Nimick, 1984; Price et al, 1985; Price, 1986).

(c) The maximum stresses are compared with the intact uniaxial comparessive (and tensile) strength (e.g., Section 3.5 of the report; also, next to last paragraph on p. 12). The Hoek-Brown uniaxial strength (Fig. 6) obviously is much lower, especially for the expected case, and certainly would not result in a ratio of 10/1.

3. The authors acknowledge that "the simplified analysis does not account for the effects of shearing along fractures" (p. 17). Bandis et al (1986) report significant (e.g., two orders of magnitude) increases in joint hydraulic conductivity for some shearing tests involving 6mm displacements.

4. No details are given in this report to allow the reader to determine whether the RMR values (48 for the lower value, 65 for the expected value) are reasonable. [Details are presumably given in the cited reference of Langkopf and Gnirk (1986)]. However, similar RMR can be arrived at independently by assuming the following:

	"lower"	"expected"
(a) intact rock	12	12
(b) RQD	8	13
(c) joint spacing	10	20
(d) joint condition	12	20
(e) ground water	10	10
Total (RMR)	52	73

5. In Section 3, elastic analyses assume a non-uniform stress state, whereas elastoplastic analyses assume a hydrostatic stress state. This situation results from reliance on closed-form solutions. No explanation is presented for restricting analysis to closed-form solutions. In Section 5, the permeability calculations also assume an isotropic stress field.

6. The literature reviewed in relation to blasting damage neglects at least one important reference—Spathis et al (1987). It is also very suprising that the G-Tunnel blasting experiments are not referenced. The literature reviewed in relation to joint permeability neglects several important references, some of which are included in the Fundamentals of Rock Joints (Proceedings of the International Symposium on Rock Joints) edited by Ove Stephansson (1985).

7. The reference to Kelsall et al (1984), on p. 4, was not included in the list of references.

8. The authors list some of the assumptions and limitations involved in using the Hoek-Brown empirical failure criteria (Section A-15, p. 67) but neglect to note some others. For example, it is not pointed out that the original reference (Hoek and Brown, 1980) did not include any tuffaceous rocks. Also, the authors cite Barton et al (1985) for justification that the residual and peak rock mass strength properties are equal. However, this reference (Barton et al, 1985) discusses strength properties of pre-existing joints. It is not clear that the strength properties of pre-existing joints should be the only factor affecting rock mass strength.

Recommendations

1. NRC should consider performing an independent determination of the effects of some of the assumptions inherent to the analysis. For example, it might be useful to examine mechanical aperture changes for a problem geometry like that given in Fig. 2 (p. 8) of this document, in which the discontinuities are explicitly modeled. Another simple analysis would be to study the stress distribution around a circular shaft in an elasto-plastic material subject to a non-uniform in-situ stress state.

2. NRC should consider requesting the following from DOE:

   (a) an updated analysis when more reliable site-specific data become available;

(b) integration of the results of these analyses into the repository performance analysis (The results should be studied to determine if a more detailed or comprehensive analysis is warranted.); and

(c) confirmation of results presented in the document by in-situ (in shaft?) testing.

3. NRC should consider having someone familiar with hydrology review the document—particularly aspects concerning unsaturated flow.

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